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Effect of Irrigation Solution Temperature on Bioceramic Sealer Bond Strength

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: Different temperature conditions can affect the efficiency of irrigation solutions and consequently the ability of canal sealers to bond to root canal walls. The aim of this endodontic study was to evaluate the effect of irrigation solutions at different temperatures on the bond strength of a bioceramic-based root canal sealer.

Material/Methods: Root canal preparations were completed through irrigation with the following solutions: Group 1 was irrigated with 5 ml NaOCl (sodium hypochlorite) +5 ml EDTA (Ethylenediamine tetra-acetic acid) (22°C); Group 2 was irrigated with 5 ml NaOCl +5 ml EDTA (37°C); Group 3 was irrigated with 5 ml NaOCl +5 ml GA (Glycolic acid) (22°C); Group 4 was irrigated with 5 ml NaOCl +5 ml GA (37°C), Group 5 was irrigated with 20 ml Dual Rinse® HEDP (Etidronate) – NaOCl mixture (22°C); and Group 6 was irrigated with 20 ml of Dual Rinse® HEDP mixture (37°C). Obtained test specimens were subjected to the push-out test. Three-way ANOVA was used to compare bond strength values.

Results: The main effect of temperature ($P<0.05$), the main effect of the solution ($P<0.05$), and the main effect of the section ($P<0.05$) were significantly associated with the mean values of the bond strength. Heating irrigation solutions increased the bond strength of bioceramic-based canal sealers.

Conclusions: The bond strengths of the solutions increased as the temperature increased. EDTA solution significantly increased the bond strength compared to Dual Rinse® HEDP solution. Meanwhile, the bond strengths in the apical region were lower than those in the middle region.

Keywords: **Chelating Agents • Temperature • Heating**

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Introduction

Bacteria that colonize the root canal through various means become more resistant to antimicrobial agents when they organize into biofilm, thereby playing a significant role in endodontic failure [1]. Optimal root canal treatment involves the disinfection of all accessible points in the root canal system and removal of infected tissues in the root canal, completed with hermetic filling of the root canal. The intention is thus to maintain healthy periapical tissues [2].

Regions such as isthmuses, oval projections, and apical deltas cannot be accessed through mechanical preparation [3]. For these inaccessible regions to be cleaned and disinfected, the shaping process must be supported with irrigation [4].

The layer covering the dentin tubules on the canal walls that is formed during canal root shaping and contains an organic and inorganic part is called the "smear layer" [5]. By reducing dentin permeability, the smear layer can prevent antibacterial solutions from reaching bacteria within the dentin tubules [6]. While different solutions are used to remove the inorganic part of the smear layer, NaOCl is used to remove the organic part [7]. The chemical agent most frequently used for removing the inorganic part is EDTA. However, EDTA adversely affects the physical and mechanical properties of the dentin, as prolonged contact of EDTA with dentin decreases the elasticity modulus and bending resistance of dentin, and this can increase the risk of root fracture [8]. The disadvantages of EDTA solution, such as decreasing NaOCl's ability to dissolve tissue [9], its insufficient removal of inorganic tissue in the apical third compared to the coronal and middle third [10], causing demineralization if it remains within the canal for more than 1 minute, and its cytotoxicity [11], led investigators to explore the use of other alternative chelators.

HEDP is a bisphosphonate, also known as 1-hydroxyetane 1,1-diphosphonic acid or etidronate. As it is a weak chelator, HEPD can be used by mixing it with NaOCl, while etidronic acid causes less damage in the dentin compared to EDTA [12]. It is thought that HEDP is the only biocompatible chelator that can be used in combination with NaOCl without altering the antimicrobial activity of NaOCl, and it is similar to EDTA in terms of smear layer removal activity [13]. GA, known as alpha hydroxy acid, is the smallest member of the organic acid group. GA is a colorless, water-soluble, and odor-free material [14]. Küçükekenci investigated the effects of different acidic irrigation solutions on the dentin bond strength of resin-based and bioceramic-based root canal fillings, suggesting that glycolic could be alternatives to EDTA [15].

One of the main factors affecting the wetting of a solid is the surface tension of the liquid. Reduction in the surface tension increases an irrigant's contact with the dentin walls of the root canal system [16]. Çiçek et al reported that pre-heating irrigation solutions decreases surface tension, enhances the ability of tissue to dissolve, and consequently increases the dentin tubule penetration of root canal sealers [17].

The first use of bioceramic materials as root canal sealer was based on the experimental study by Krell and Wefel, in which they compared the physical sealing properties of calcium phosphate cement with Grossman's sealer on extracted teeth [18]. Bioceramic-based canal sealers, which are considered to be biocompatible, are frequently preferred due to their high dimensional stability as a result of hardening in the moist root canal environment due to their hydrophilic structure, as well as the advantages they can offer, such as ability to reach lateral canals, good penetration through spreading into the intra-canal irregularities, and high bond strength due to chemically bonding to the dentin [19-21]. However, one of the major disadvantages of using bioceramic-based sealers is the difficulty encountered when they need to be removed from the root canal for various reasons [22].

Push-out bond strength has been used to evaluate the bond strength of various filling materials to root dentin [23]. This test is used to assess the interfacial shear strength between 2 surfaces and evaluating their adhesive properties and resistance to dislodgement [24]. A few studies have assessed the effect of irrigation solutions on the push-out bond strength of bioceramic-based sealers [25-28]. However, no data are available on the effects of different temperature of irrigation solutions on the bond strength of bioceramic-based sealers. Therefore, the present study compared the effects of EDTA, GA, and HEPD at different temperatures on the bond strength of a bioceramic-based root canal sealer.

Material and Methods

Ethics Approval

The study used 72 mandibular premolar teeth with a single root and a single canal that had been extracted for orthodontic and periodontal reasons at the oral and maxillofacial surgery clinic. All procedures were performed by a single operator to ensure standardization. Ethics committee approval for the current study was obtained with Decision No. 2023/18 of the Local Ethics Committee of Dicle University Faculty of Dentistry.

The Null Hypothesis

The null hypothesis of our study was that the use of different chelating agents at room temperature and body temperature would have no effect on the bond strength of the bioceramic-based canal sealer to dentine.

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Calculation of Sample Size

To determine the number of patients' teeth required for our study, the sample size was calculated using the G Power 3.1 package program (Heinrich-Heine-Universitat Düsseldorf, Düsseldorf, Germany). According to ethics rules, when the test power is taken as the minimum value of 80%, 10 specimens in each group and a total of 60 specimens in 6 groups must be obtained (effect size f=0.4328217). Assuming a dropout rate of 20%, 12 specimens in each group and a total of 72 specimens in 6 groups were used in our study.

The criteria for the teeth selected were complete root development, absence of intra-canal calcification, absence of any fracture, crack, and internal or external resorption on the root surface, and maximum root inclination of 10°. The teeth selected were separated from the crowns using a diamond fissure bur (ISO 806314, 014, Meisinger, Germany) under water cooling to a length of 15 mm to ensure standardized application.

Root Canal Preparation Procedures

To obtain the Dual Rinse HEDP solution used in the study, 1 capsule containing 0.9 g HEDP was added to 10 ml of 5% NaOCl solution and the solution was mixed for 2 minutes with a magnetic stirrer.

Guided by previous similar studies [25,29-31], the working length of the roots was adjusted to be 1 mm shorter than the length of K-file no. 15 (Dentsply Maillefer, Ballaigues, Switzerland) as seen through the apical foramen. Following pre-enlargement with 15 K and 20 K files, root canal shaping was completed with Reciproc R25 and R40 Ni-Ti files (VDW, Munich, Germany). The canal preparation was completed using an X-Smart Plus (Dentsply Maillefer, Ballaigues, Switzerland) endodontic motor in "Reciproc ALL" mode in accordance with the manufacturer's recommendations. At each file change, the teeth to be sequentially chelated were irrigated with 10 ml of 5% NaOCl (Microvem, Istanbul, Türkiye) at 22°C and 37°C, and the teeth to be continuously chelated were irrigated with Dual Rinse® HEDP (Medcem, Weinfelden, Switzerland) combined with 10 ml of 5% NaOCl at 22°C and 37°C. The teeth were prepared for final irrigation following completion of the preparation. They were then randomized into 6 groups with 12 teeth in each group by simple random sampling (n=12). Root canal preparations were completed through irrigation with the following solutions:
Group 1: The teeth were irrigated with 5 ml 5% NaOCl at 22°C, followed by 5 ml of distilled water. For the final irrigation, 5 ml 17% EDTA (Saver, Prime Dental Products PVT Ltd., Maharashtra, India) solution at 22°C was applied for 1 minute.
Group 2: The same as with the previous method, the teeth were irrigated with 5 ml of 5% NaOCl at 37°C.
Group 3: The teeth were irrigated with 5 ml of 5% NaOCl at 22°C, followed by 5 ml of distilled water. For the final irrigation, 5 ml of 17% GA (Sigma-Aldrich, Saint Louis, MO, ABD) solution at 22°C was applied for 1 minute.
Group 4: The same as with the previous method, the teeth were irrigated with 5 ml of 5% NaOCl at 37°C, followed by 5 ml of distilled water. For the final irrigation, 5 ml of 17% GA solution at 37°C was applied for 1 minute.
Group 5: During the canal preparation, Dual Rinse® HEDP combined with 10 ml of 5% NaOCl was used at 22°C.

For the final irrigation:
The teeth were prepared for canal filling by irrigating them with 10 ml of 5% NaOCl at 22°C + DualRinse HEPD.
Group 6: During the canal preparation, Dual Rinse® HEDP combined with 10 ml of 5% NaOCl was used at 37°C.

For the final irrigation:
The teeth were prepared for canal filling through irrigation with 10 ml of 5% NaOCl at 37°C + Dual Rinse® HEPD.

For all study groups, to avoid damaging the dentin structure or causing heat increase, passive ultrasonic irrigation (PUI) was applied for 30 seconds at 45 kHz frequency with Ultra-X ultrasonic activator (Eighteeth, Changzhou City, China), and the teeth washed with 5 ml of distilled water were prepared for canal filling. During all irrigations, a 31-gauge (G) (Ultradent Products Inc., South Jordan, UT) side-vent irrigation needle was used.

Following the final irrigation procedure, the canals were dried with paper points and filled with AH Plus Bioceramic sealer (AHBC; Dentsply Sirona, York, PA, USA) using the single-cone technique. The filled teeth were kept in an oven providing a 37°C environment at 100% humidity for 1 week. The method schematizes the process, providing a visual framework that simplifies the complexity of the described mechanism (**Figure 1**).

After the tooth roots were embedded in cold-cured acrylic resin (Imicryl SC; Imicryl Dental Materials, Inc, Türkiye), 2 horizontal sections of 1 mm thickness were taken from the apical 2-mm and 5-mm levels of the roots using a 0.3-mm thick diamond separator (Metkon, Microcut-Precision cutter, Türkiye) on the precision cutter (Isomet 1000, Buehler, Lake Bluff, IL, USA) rotating at a low speed (100-250 rpm) under water cooling. Thus, a total of 144 specimens were obtained, 24 in each group (**Figure 2**).

Specimen Preparation

The specimens were placed on an acrylic baseplate with a center hole to allow free movement of the tip of the piston. They then underwent a push-out test using a Universal Testing Machine (Instron, Canton, MA, USA) with a loading rate of 1

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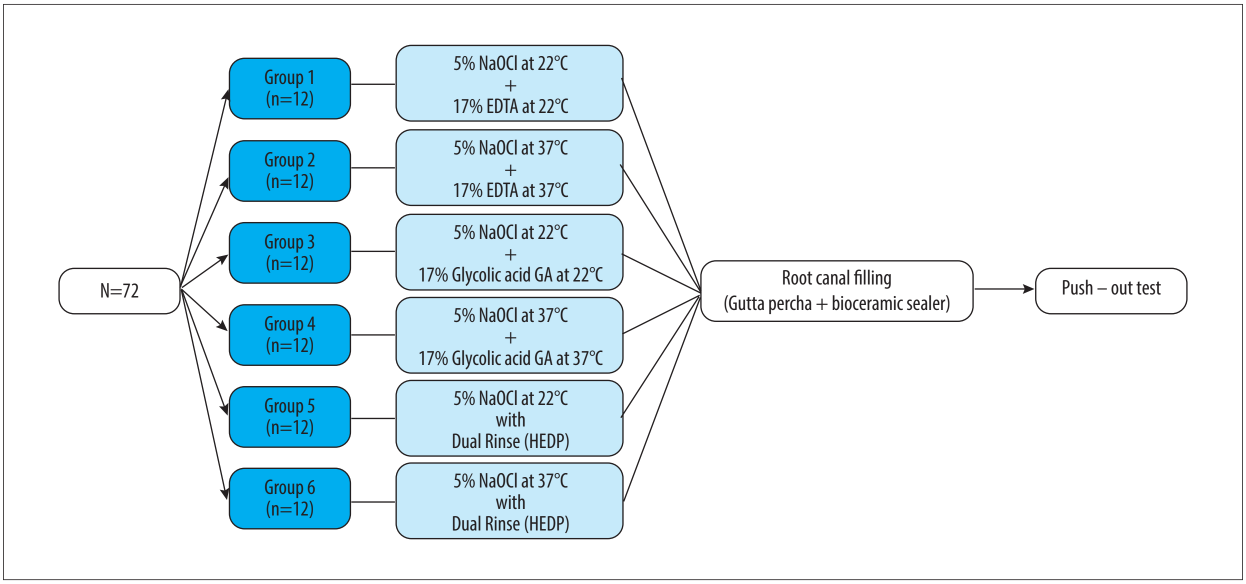

Figure 1. Methods used. *The figure was created by Canva for Eucation application.*

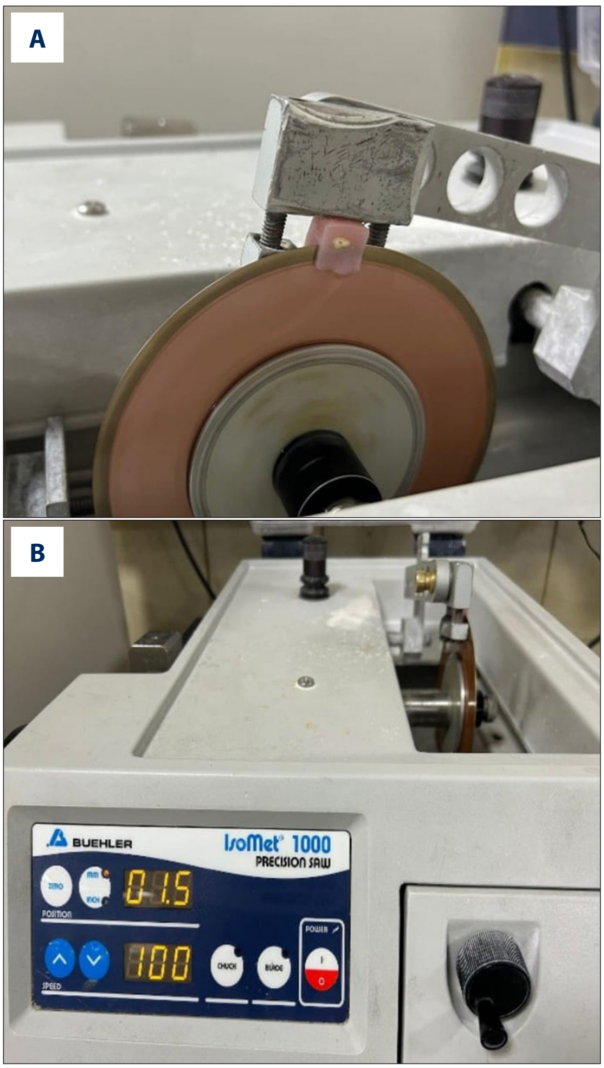

Figure 2. Implementation of the push-out test on the specimens after sectioning with an Isomet device. (**A**) Sectioning process with the Isomet device, (**B**) Isomet device settings, (**C**) Application of the push-bond strength test to sample sections. *The photographs in Figure 2 were combined using the Paint program (Microsoft Office). No other software was used.*

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Table 1. Comparison of bond strength (MPa) values depending on solution, temperature, and section.

	KT	SD	KO	F	P	η^2
Solution	3.39	2	1.69	4.08	0.020	0.06
Temperature	26.08	1	26.08	62.74	<0.001	0.32
Section	32.24	1	32.24	77.56	<0.001	0.37
Solution*Temperature	1.80	2	0.90	2.17	0.120	0.03
Solution*Section	0.20	2	0.10	0.24	0.790	0.00
Temperature*Section	3.19	1	3.19	7.67	0.010	0.05
Solution*Temperature*Section	0.20	2	0.10	0.25	0.780	0.00

Three-way ANOVA; KT – sum of squares; SD – degree of freedom; KO – mean square, η^2 – partial eta squared.

mm/minute, and a stainless-steel test tip with a diameter of 0.8 mm on the middle third and 0.3 mm on the apical third compatible with the diameter of the canal filling.

The computer automatically detected decrease in resistance against the applied force following dislocation of the material being subjected to vertical force by the test lead, and the highest force value was recorded in Newtons (N) and converted into megapascals (MPa) with formula MPa=Newton/π (r_1+r_2) h (h=the thickness of the sample, r_1=the apical radius of the root canal, r_2=the coronal radius of the root canal).

Results

Statistical Analysis

The data were analyzed with SPSS software version 23 (IBM Corp, Armonk, NY, USA). Since the number of samples per group was below 30, the Shapiro-Wilk test was used as the reference in the normality assessment. According to this test, as the *P* value was above 0.05, it was determined that the data followed a normal distribution. Three-way ANOVA was used to compare those bond strength values compatible with the normal distribution depending on the solution, temperature, and section. Any multiple comparisons were evaluated using the Bonferroni correction. The results are presented as mean±standard deviation, with the significance level taken as $P<0.05$.

Effect of Temperature

All variables were normally distributed and this allowed for the use of parametric tests. According to the results of the three-way ANOVA, when the irrigation solutions temperatures were compared, the main effect of the temperature was statistically significant on the mean values of the bond strength ($P<0.001$). The mean value of the bond strength at 22°C was 1.3 MPa, versus 2.1 MPa at 37°C. Solutions applied at 37°C significantly increased the bond strength compared to those applied at 22°C ($P<0.05$) (**Table 1**).

Effect of Solution

The main effect of the solution was found to be statistically significant on the mean values of the bond strength ($P=0.020$). The mean values of the bond strength were 1.6 MPa, 1.9 MPa, and 1.6 MPa in a Dual Rinse® HEDP solution, EDTA, and GA, respectively. While there was no significant difference between the Dual Rinse® HEDP and GA solutions and between the EDTA and GA solutions ($P>0.05$), the EDTA solution significantly increased the bond strength compared to the Dual Rinse® HEDP solution ($P<0.05$).

Effect of Section

The main effect of the section was statistically significant on the mean values of the bond strength ($P<0.001$). The mean value of the bond strength on the apical section was 1.2 MPa versus 2.2 MPa on the middle section. The bond strength was significantly greater in the middle section than in the apical section ($P<0.001$).

The interaction between temperature and section was statistically significant on the mean values of the bond strength ($P=0.010$). (**Table 2**). The mean MPa value obtained at 37°C in the middle section was significantly higher than the values obtained at 22°C in the apical section and in the middle section, and at 37°C in the apical section ($P<0.05$). There was no significant difference between the values obtained at 22°C in the middle section and at 37°C in the apical section ($P>0.05$). The lowest values obtained in the interaction between temperature and section were at 22°C and in the apical section, significantly lower than that of the other interactions ($P<0.05$).

Any failures following the push-out bond strength test were examined under a Zeiss Stemi 2000-C Stereomicroscope (Zeiss,

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Table 2. Descriptive statistics of the bond strength values depending on solution, temperature, and section.

Temperature	Section	Solution			Total
		Dual Rinse	EDTA	GA	
22°C	Apical	1.0±0.7	1.1±0.5	0.8±0.3	1.0±0.5[x]
	Middle	1.6±0.8	1.8±0.7	1.4±0.7	1.6±0.7[y]
	Total	1.3±0.8	1.4±0.7	1.1±0.6	1.3±0.7
37°C	Apical	1.3±0.3	1.8±0.5	1.4±0.7	1.5±0.6[y]
	Middle	2.4±0.8	3.0±0.6	2.8±0.8	2.8±0.8[z]
	Total	1.9±0.8	2.4±0.8	2.1±1.0	2.1±0.9
Total	Apical	1.2±0.5	1.4±0.6	1.1±0.6	1.2±0.6
	Middle	2.0±0.9	2.4±0.9	2.1±1.1	2.2±0.9
	Total	1.6±0.8[a]	1.9±0.9[b]	1.6±1.0[ab]	1.7±0.9

Mean±standard deviation (a-b, x-z: there is no significant difference between values with the same letters). EDTA – ethylenediamine tetra-acetic acid; GA – ghlycolic acid; NaOCl – sodium hypochlorite; Dual Rinse® HEDP – etidronate powder.

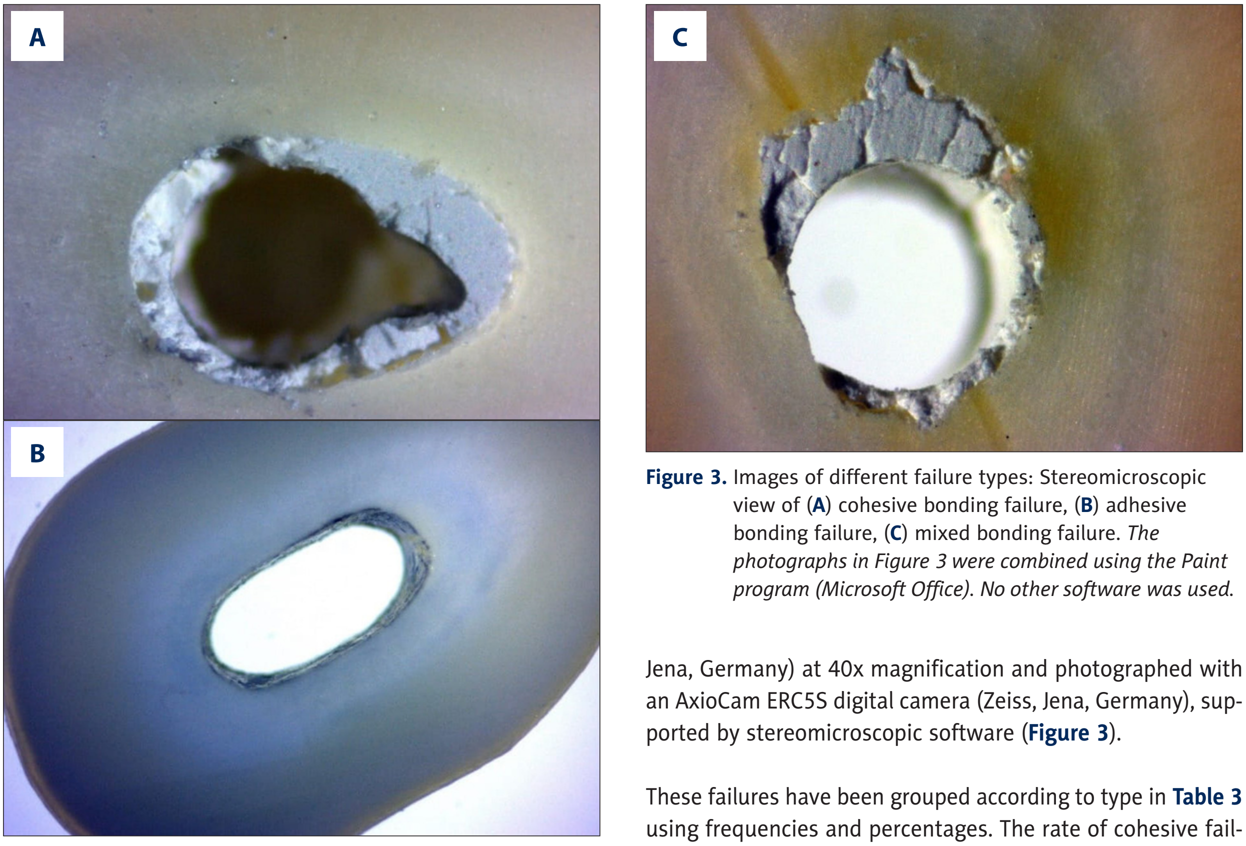

Figure 3. Images of different failure types: Stereomicroscopic view of (**A**) cohesive bonding failure, (**B**) adhesive bonding failure, (**C**) mixed bonding failure. *The photographs in Figure 3 were combined using the Paint program (Microsoft Office). No other software was used.*

Jena, Germany) at 40x magnification and photographed with an AxioCam ERC5S digital camera (Zeiss, Jena, Germany), supported by stereomicroscopic software (**Figure 3**).

These failures have been grouped according to type in **Table 3** using frequencies and percentages. The rate of cohesive failure was highest (50%) in the 17% GA at 37°C and 5% NaOCl at 22°C + HEDP groups. The rate of adhesive failure was highest (25%) in the 5% NaOCl at 22°C + HEDP group. The rate of mixed failure was highest (50%) in the 17% EDTA at 22°C and 17% EDTA at 37°C groups.

Table 3. Frequency and percentage of adhesive, cohesive, and mixed-type bonding failures by chelator group.

GROUPS	ADHESIVE	COHESIVE	MIXED
17% EDTA at 22°C	1 (8.4%)	5 (41.6%)	6 (50%)
17% EDTA at 37°C	1 (8.4%)	5 (41.6%)	6 (50%)
17% GA at 22°C	2 (16.7%)	5 (41.6%)	5 (41.6%)
17% GA at 37°C	1 (8.4%)	6 (50%)	5 (41.6%)
5% NaOCl at 22°C + HEDP	3 (25%)	6 (50%)	3 (25%)
5% NaOCl at 37°C + HEDP	2 (16.7%)	5 (41.6%)	5 (41.6%)

EDTA – ethylenediamine tetra-acetic acid; GA – glycolic acid; NaOCl – sodium hypochlorite; Dual Rinse® HEDP – etidronate powder.

Type of Failure

When we look at the bonding failures in all specimen groups of the study, mixed bonding failure was (41.7%), cohesive failure was (44.4%), and adhesive bonding failure was (13.9%). Mixed failure was nearly at the same level as cohesive failure. Adhesive failure was substantially lower compared to all groups. Stereomicroscopic images of the failure types of the samples as a result of the push-in bond strength test are shown in **Figure 3**.

Discussion

Our study revealed that the use of irrigation solutions at different temperatures during root canal treatment influences the bond strength of bioceramic canal sealers. Although EDTA solution increased dentin bond strength more than Dual Rinse® HEDP, no significant difference was found between Dual Rinse® HEDP and glycolic acid and EDTA and glycolic acid. The null hypothesis of our study was that the use of different chelating agents at room temperature and body temperature would have no effect on the bond strength of the bioceramic-based canal sealer to dentine.

This hypothesis was rejected. Temperature increase enhanced the strength of the bond of the bioceramic canal sealer with the walls of the root canal.

Although there is currently no perfect irrigation solution that has all the desired characteristics, NaOCl is considered to be the organic tissue solvent closest to the ideal thanks to its advantages, such as being a strong antiseptic agent, efficacy against biofilm, and being economical [32].

The sequential application of NaOCl and EDTA is known to cause erosion in peritubular and intertubular dentin while removing the smear layer and limits the antibacterial capacity of NaOCl [33]. The use of EDTA and strong acids such as CA or IP6 during shaping can lead to procedural errors such as perforation or step formation. In addition, the combined use of these strong acids also affects the ability of NaOCl to dissolve organic tissue, and its antimicrobial activity. To eliminate all these problems and save time by preventing smear layer formation, continuous chelation using a combination of a weak acid and NaOCl is recommended [34,35].

Heating low-concentration solutions enables irrigation solutions to better penetrate dentin tubules by decreasing surface tension, and ensures effective removal of the smear layer [17,36,37]. In a study evaluating the bond strength of fiber posts, higher POBS values were obtained when pre-heated irrigation solutions were used compared to unheated solutions [38]. These results support the results of our study and indicate that temperature increase leads to higher POBS values.

In a study by Sfeir et al [29] evaluating AH Plus Jet and Total Fill BC Sealer canal sealers with the POBS test following final irrigation with EDTA, NaOCl, and Dual Rinse® HEDP solutions, the HEDP/Total Fill BC sealer group demonstrated significantly lower push-out bond strength values, while the EDTA/Total Fill BC sealer group demonstrated significantly higher push-out bond strength values compared to the HEDP/Total Fill BC sealer and NaOCl/AH Plus Jet groups. They reported that use of a strong chelator, such as EDTA, as the final irrigation solution following the continuous chelation–irrigation protocol with HEDP, optimizes the root attachment of resin-based canal sealers [39]. In line with these results, our study found that the bioceramic-based canal sealer had a higher bond strength in the EDTA (1.9±0.9 MPa) group compared to the HEDP (1.6±0.8 MPa) group regardless of temperature changes.

Özata et al [25] evaluated the effect of IP6, EDTA, and GA when used as final irrigation solutions on the push-out bond strength of Well Root ST, a bioceramic material, and found no significant difference between the 3 chelators. Okumus et al [40] studied the smear removal activity and amount of dentin erosion of 17% EDTA, 10% GA, and 18% HEDP activated by PUI

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and reported that the smear removal activity of the chelating agents was similar in the specimens using the PUI activation method. In contrast, in a previous study evaluating the effects of different acidic irrigation solutions on the bond strengths of root canal fillings, higher bond strength values were obtained in the glycolic acid group compared to the EDTA group [15]. In our current study, although the Total EDTA group bond strength values (1.9±0.9 MPa) were relatively higher than the Total GA group bond strength values (1.6±1 MPa), regardless of the temperature, there was no statistically significant difference in terms of POBS values between the EDTA and GA groups. The reason our study's results were different may be due to the fact that ultrasonic activation was not performed in the previous study.

The layer called the mineral infiltration zone is an intermediate surface layer formed by calcium silicate-based sealers on the wall of root dentin. Adhesion between the sealer and dentin is provided by this chemical interaction on the interlayer dentin and mechanical interaction with tag-like structures [41-43]. Our findings suggest that the increased bond strength of the bioceramic-based root canal sealer to dentine after chelating at 37°C compared to 22°C can be attributed to better penetration of the root canal sealer into the more exposed dentinal tubules and increased adhesion. In addition, since dentinal tubule density in the middle region was higher than in the apical region, chelators might have had higher bond strength by exposing a greater number of dentinal tubules in the middle region.

De Hemptinne et al [44] reported that irrigation agents at room temperature conditions (20.7±1.2°C) take 240 seconds to reach body temperature (35±0.9°C) after injection into the canal. Considering that chelation agents are applied for a short time in the chelation process due to their demineralization effects in the canal, heating them to body temperature before application will optimize their effectiveness. Çiçek et al [17] assessed the smear layer removal effectiveness of EDTA and MTAD, finding that use of these solutions at 25°C and 37°C was more effective than at 4°C. Similarly, Uzunoğlu et al [45] investigated the effect of increasing temperatures of QMix and EDTA on the push-in bond strength of epoxy resin-based root canal sealer, and found higher bond strength values with irrigation at 37°C EDTA than with irrigation at 22°C EDTA. In our study, it is thought that the reason why the strength of the bond of the bioceramic-based canal sealer with the dentin was more effective following chelation at 37°C compared to 22°C is better penetration and increased adhesion of the canal sealer with the more widely opened dentin tubules.

The hydrophilic nature of bioceramic sealers and the hydrophobic surface of the gutta-percha may affect POBS, which could explain why cohesive failures were most frequently observed in our study than in previous studies [46,47].

Although it was possible to evaluate the dissolution activity activated by the irrigation solutions at different temperatures under in vitro conditions, the study's limitations were the fact that the solution temperature within the oral environment returned to body temperature [44], and consequently, the temperature range was kept close to body temperature in the study groups.

The literature lack consensus on the optimal dentin disc thickness of the samples used in the POBS test. Although 1-mm slices were used in our study to enhance the friction force, studies in the literature recommend a range of thicknesses of 1-4 mm [48-50]. Moreover, in addition to disc thickness, the elastic modulus and size of the material examined can also significantly affect bond strength, which is another limitation of our study [51].

Conclusions

The present study demonstrated that heating irrigation solutions used for root canal treatment within physiological limits increases the bond strength of bioceramic-based canal sealers. EDTA has a higher chelating capacity than Dual Rinse® HEDP. Chelators have a greater effect in the middle region than the apical region. Due to the current limitations of push-out bond strength study design, further research is needed on the use of EDTA, GA and Dual Rinse® HEDP solutions at different temperatures and using a continuous chelation protocol.

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Declaration of Figures' Authenticity

All figures submitted have been created by the authors, who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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